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Winter Cover Crop and Management Effects on Summer and Annual Nutrient Yields

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ABSTRACT

Effluent from a swine *(Sus scrofa domesticus*) lagoon is often applied repeatedly to nearby fields because of logistical constraints and costs of transportation. To minimize accumulation of soil nutrients and sustain use of spray field, best management practices must maximize the rates of removal of manure nutrients. Research determined summer hay and nutrient yields of bermudagrass [*Cynodon dactylon* (L.) Pers.] following winter cover crops 'Kenland' red clover (*Trifolium pratense* L.), 'Bigbee' berseem clover (*T. alexandrinum* L.), or 'Marshall' annual ryegrass (*Lolium multiflorum* Lam.) subjected to five harvesting systems. Also, summer and winter forage yields were combined and analyzed to find best annual performance. Nutrient yields of bermudagrass were statistically affected by winter cover crop species and harvest date. Summer production was maximized following berseem clover harvested on a two-harvest-day system of 15 May and 1 June. Harvesting the winter cover crop in addition to the bermudagrass increased extraction of N (82%), P (76%), K (90%), Mg (95%), Mn (67%), Ca (158%), Fe (80%), Zn (83%), and Cu (97%). For environmentally sensitive nutrients N, P, Cu, and Zn, annual yields were maximized with a two-harvest-day system of 15 April and 1 June of a cover crop, which was not the best harvest system for either the winter or the summer trials in isolation. Tests on summer performance and winter performance in isolation were informative and did indicate the best winter cover crop species, berseem clover, but did not indicate the best management system for annual production.

FERTILIZATION of a forage crop with animal manure at rates to meet the N requirements of the crop results in an over application of P. This is the result of animal manure having an N/P ratio in the range of 1:1 to 4:1 whereas ratio for nutrients extracted in the harvested forage varies from 5:1 to 12:1. With repeated applications of this relatively high P fertilizer, the soil P levels attain the critical level or change point and the result is excessive P leaching with any substantial rain (Hesketh and Brookes, 2000). Even when the change point is not attained, P may leach into shallow ground water via preferential flow (van Es et al., 2004). As soil concentrations of manure P increase, the probability of nutrient pollution of surface water and eutrophication of ponds or lake is increased. To manage this hazard in the Mid-South, where severe rain events are frequent in the winter, a winter cover crop is recommended to protect soil surface from erosion and to capture available nutrients.

In swine production, the waste in the swine lagoon is commonly land applied via summer irrigation to nearby forages, which are harvested for hay. Transporting this liquid waste to more distant fields is logistically difficult and prohibitively expensive. It is critical that best management practices be developed for removal of maximum amounts of manure nutrients in harvested forage from fields to which swine manure effluent is applied. Surveys indicate the inequality between rate of nutrient removal and manure nutrient application is leading to accumulation of manure nutrients in the soil. In the South, Ribaudo et al. (2003) estimated the percentage of swine farms with less than 300 animal units that meet the N-based standard for land application is 32% and the farms meeting P-based standard for land application is 12%. For larger farms the percentage of farms meeting the N-based or P-based application rate is lower.

A common, summer perennial forage of the Mid-South, which is fertilized with swine effluent is bermudagrass (Brink et al., 2001). This is the species of choice for many southern farmers because this grass is aggressive, responds rapidly to fertilization, has good feed value, and tolerates drought. Common bermudagrass fertilized with swine effluent has been shown to perform very well in comparisons with 'Costal' hybrid bermudagrass, Eastern gammagrass (*Tripsacum dactyloides* L.), indiangrass [*Sorghastrum nutains* (L.) Nash], johnsongrass [*Sorghum halepense* (L.) Pers.], and switchgrass (*Panicum virgatum* L.) for quantity of nutrients extracted from the soil (McLaughlin et al., 2004). None of the other perennial, summer grasses exceeded the common bermudagrass yield of nutrients or hay and most were significantly less productive.

The harvesting of a winter cover crop of annual ryegrass has been proposed for remediation or control of soil nutrient concentrations (Brink and Rowe, 1999). Alternative winter cover crops have been evaluated and with a single spring harvest, annual ryegrass removed as much or more P than three grains and 12 legumes in fields fertilized for many years with poultry litter (Brink et al., 2001). Brink et al. (2001) estimated harvesting the winter cover crop increases the total P removal by 10 to 25% over that removed with harvesting only the summer forage. Since harvesting date does affect feed value and hence the nutrient concentration of the forage, a test was conducted using two harvest dates in the spring and comparing that response to the single harvest. A two-harvest-day of 1 April and 1 June for the winter cover crop 'Bigbee' berseem clover, the P, Cu, and Zn removal rates were increased by 24, 40, and 72%, respectively, over the single harvest of annual ryegrass (Rowe and Fairbrother, 2003).

A 12-mo agronomic management system for the swine effluent spray field requires double cropping of summer and winter forages. Choice of summer and winter species is difficult because compatibility of the crops planted in tandem is greatly affected by the manage-

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ment practices (Moore et al., 2004). Potentially, a high yielding winter cover crop might compete and negatively impact early growth or persistence of the summer forage. The best management system, which is in this case the harvest dates, and the choice of species to use as a winter cover may not be the best system on an annual basis if summer forage productivity is impaired by spring growth. For sustained, safe use of the swine effluent spray field, the annual management of nutrients is critical, not just the summer or winter yields.

The first objective of this research was to determine any residual effects of three winter cover crops and/or their harvesting management system on summer productivity of common bermudagrass. Second objective was to combine measurements of summer yields with the winter yields reported in an earlier manuscript (Rowe and Fairbrother, 2003) to determine the best 12-mo management system for maximizing manure nutrient extraction.

MATERIALS AND METHODS

This 3-yr study was conducted at a commercial swine farm near Pheba, MS (33°35′ N, 88°56′ W) on a Prentiss loam (coarse-loamy, siliceous, semiactive, thermic Glossic Fragiudult). In the prior 5 yr, the producer established a common bermudagrass sod and fertilized the area using a center pivot irrigation that pumped swine effluent from a single-stage anaerobic lagoon. Each summer the field was regularly irrigated in 1-cm increments (because of regulations preventing puddles) with a total of about 15 cm of effluent applied each summer, which had nominal nutrient concentrations of 300 to 420 mg N L^{-1} and about 60 mg P L^{-1}. The annual fertilization rates were 520 kg N ha^{-1} and 110 kg P ha^{-1}. In the effluent, the N is approximately 84% NH_4/NH_3 and the P is 80% water soluble ortho-P (Adeli and Varco, 2001). Beginning in the fall of 1997, plots (2 by 4 m) of dormant bermudagrass sod were planted with one of three winter cover crops: 'Kenland' red clover, 'Bigbee' berseem clover, or 'Marshall' annual ryegrass. The red clover was managed as an annual. The winter forages were harvested either as a single 1 June harvest or one of four two-harvest-day systems: 1 April and 1 June, 15 April and 1 June, 1 May and 1 June, and 15 May and 1 June. (The four two-harvest-day systems are referenced hereafter by the date of the first harvest, i.e., 1 April, 15 April, etc.) The herbage was weighed and subsampled for determination of moisture and nutrient concentrations. More detail on the management of these winter forages was reported by Rowe and Fairbrother (2003). The test on winter cover crops and their management was a factorial design of five harvesting regimes by three winter forages replicated four times in a split-block design with harvesting system as the whole plot. Each year a new randomization of the treatments was applied to the plots. Bermudagrass yields for the summer following the winter annual treatments had three or four harvests on 35-d intervals. Even with irrigation, drought eliminated the final and fourth harvest in 1998 and in 2000.

For each harvest, a 0.9-m swath through the center of each plot of bermudagrass was cut at 5 cm height with a sickle bar mower. The forage was weighed and subsampled for determination of moisture and nutrient concentrations. Subsamples were dried at 65°C for 48 h, ground to pass through a 1-mm screen, and then sealed in plastic containers. Nitrogen content of forage was determined with duplicate samples using an automated dry-combustion analyzer (Model NA 1500 NC, Carlo Erba, Milan, Italy). Concentrations of P, K, Ca, Cu, Fe, Mg, Mn, and Zn were estimated on duplicate subsamples following the procedure of Brink et al. (2001): duplicate 1-g subsamples were ashed at 500°C for 4 h, and then 1.0 mL of hydrochloric acid (aqueous HCl) and purified water was added to the crucible. This was filtered after 1 h in the double acid solution (83 mL HCl and 14 mL H_2SO_4 brought to 20 L with purified water). The eight nutrients were measured by emission spectroscopy on an inductively coupled, dual axial Argon plasma spectrophotometer (Thermo Jarrell Ash Model 1000 ICAP, Franklin, MA).

Forage yields are reported on a dry weight per hectare basis for the total summer harvest of bermudagrass. Nutrient extraction was estimated as the product of nutrient concentration in the hay and hay yield for each plot at each harvest and then summed for all harvests. Statistical analysis was executed with SAS procedures (SAS Institute, 1998) on a data set that was balanced and complete. Appropriate error terms were used to test for significant effects reflecting the randomization restrictions of the split-plot design (Hinkelmann and Kempthorne, 1994) and most interactions with blocks were pooled into the error term. Means separations were estimated for fixed effects using Fisher LSD with $\alpha = 0.05$ criteria.

To determine annual performance, the yields of hay and nutrients of harvested winter cover crops reported earlier (Rowe and Fairbrother, 2003) were added plot by plot to the currently reported summer yields of bermudagrass. Statistical analysis and means separations were then performed on the 12 mo yields as they were for the summer yields.

RESULTS AND DISCUSSION

Summer Performance

The parameters included in the analysis of variance are of two types. First are the variables winter forage and harvest system, which were applied to the plots during the prior winter. Second is the random effect of year, which is primarily the climate for that particular summer. The response variables are yields of hay and eight nutrients from the summer bermudagrass grown on plots previously exposed to treatments of cover crop and harvest system.

Yield of summer hay varied between years reflecting large differences in moisture availability in late summer (Fig. 1). Average annual hay yields in 1998 and 2000 with three harvests were 9.79 and 8.83 Mg ha^{-1}, respectively. In 1999 the late summer moisture stress was minimal and the plots were harvested four times with a 50%

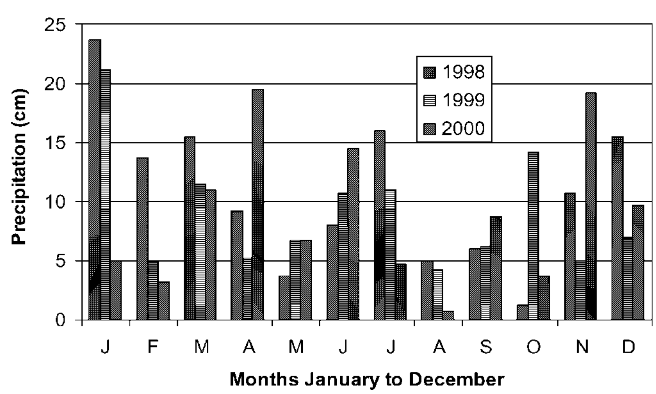

Fig. 1. Monthly rainfall for 1998, 1999, and 2000.

Table 1. Tests for significant statistical effects on hay yield and nutrient yields with three winter forages harvested with five protocols over 3 yr and the summer yields following winter cover crop. Analysis is for summer yields (SU) and annual yields (AN), which is total yield for summer bermudagrass and one of the winter cover crops exposed to one of five harvesting systems during the spring.

	Measured yields																			
	Hay		N		P		K		Mg		Mn		Ca		Fe		Zn		Cu	
Effect	SU	AN	SU	AN	SU	AN	SU	AN	SU	AN	SU	AN	SU	AN	SU	AN	SU	AN	SU	AN
Block	–		–		–		–		–		–		–		–		–		–	
Year	**	**	**	**	**	**	**	**	**	*	**	**	**	*	**	**	**	**	**	*
Harvest	**	**	**	**	**	**	**	**	ns	ns	*	*	*	ns	*	ns	**	**	*	*
Harvest × year	*	**	ns	**	**	**	**	**	ns	**	ns	*	ns	*	ns	*	ns	*	ns	**
Error b	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Forage	**	**	**	**	**	**	**	**	**	**	**	**	**	**	ns	**	**	**	*	**
Year × forage	ns	**	ns	**	*	**	**	**	**	**	ns	*	**	**	ns	*	ns	**	ns	**
Harvest × forage	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	*	ns	ns	ns	ns	ns	ns	ns
Year × forage × harvest	ns	ns	*	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	**	ns	ns	ns	ns	ns	ns

*** Indicates statistical significance of effect at $\alpha = 0.05$.**
**** Indicates statistical significance of effect at $\alpha = 0.01$.**

increase of hay yield (14.05 Mg ha^{-1}). This year-to-year variation in summer hay production translated into significant differences in yields of nutrients so the year effect (Table 1) was statistically significant for all responses. This variation between years is typical of the volatile and often stressful Mid-South climate.

The analysis of variance indicates a statistically significant main effect of winter forage species on all yields of bermudagrass except for Fe (Table 1) and a statistically significant main effect of winter harvest date on all yields except for Mg. Fortunately for interpretations, some two-way and three-way interactions were not significant. The three way interaction of year × forage × harvest date was not significant except for yield of N and this impacts generalizations about harvest system and cover crop species. The two-way interaction of harvest system × forage species was not significant except for yield of Ca and interaction of forage × year was significant only for yields of P, K, Mg, and Ca. Thus, generalization about ranking of forage yields was sometimes affected by year, which is probably a moisture effect, but little affected by harvest system. For the parameter of harvest system, the three-way interaction with forage and year was significant, again, only for yield of N and the interaction with forage was significant only for Ca yield. The harvest × year interaction was statistically significant for yields of hay, P, and K. Though significant interactions indicate generalizations about main effects should be

Table 2. Yields of hay and nutrients from summer bermudagrass following a winter cover crop of berseem clover (BC), red clover (RC), or annual rye grass (RG) with five harvesting systems.

	Hay yield			N			P			K		
First harvest date	BC	RC	RG	BC	RC	RG	BC	RC	RG	BC	RC	RG
	Mg ha^{-1}			kg ha^{-1}								
1 April	10.13C†	9.94C	9.52B	196B	210A	178B	29.6C	27.9C	28.0B	252B	252B	217B
15 April	11.85B	11.14AB	11.03A	214AB	220A	209A	37.0A	30.9AB	32.2A	332A	281A	260A
1 May	12.02B	10.57ABC	10.08AB	223AB	200A	181AB	35.6AB	30.5AB	30.9AB	303AB	252B	235AB
15 May	13.51A	11.58A	11.05A	236A	216A	202AB	37.9A	32.0A	32.2A	215A	267AB	245AB
1 June	10.13C	10.33BC	9.93AB	201B	210A	184AB	31.8BC	29.2BC	29.7AB	286AB	258AB	230AB
Means	11.63a‡	10.71b	10.32b	213a	213a	190b	34.3a	30.1b	30.6b	298a	262b	237c

	Mg			Mn			Ca			Fe		
Harvest date	BC	RC	RG	BC	RC	RG	BC	RC	RG	BC	RC	RG
	kg ha^{-1}			g ha^{-1}			kg ha^{-1}			g ha^{-1}		
1 April	15.3B	16.0A	12.8C	1181AB	925B	850C	30.0C	39.2A	28.3B	607B	593A	546B
15 April	17.7AB	16.3A	15.6A	1248AB	1100A	1123A	33.8ABC	35.5AB	32.7A	647AB	621A	668A
1 May	17.0AB	15.2A	13.3B	1236AB	950AB	959BC	35.4AB	33.0B	28.9AB	635AB	607A	544B
15 May	18.9A	15.5A15.0AB	1288A	1093A	1050AB	38.4A	36.5AB	32.7A	714A	646A	607AB	
1 June	17.5AB	15.9A	13.9ABC	1008B	975AB	936BC	31.5BC	39.6A	29.8AB	603B	635A	577AB
Mean	17.3a	15.8b	14.1c	1192a	1008b	983b	33.9b	36.8a	30.5c	641a	620ab	588c

	Zn			Cu		
	BC	RC	RG	BC	RC	RG
	g ha^{-1}					
1 April	211B	207C	206B	49.5C	48.1B	43.9B
15 April	268A	233AB	236A	59.4A	55.8A	52.6A
1 May	255A	228ABC	222AB	55.8AB	48.4B	50.6AB
15 May	271A	241A	236A	53.7ABC	50.7AB	44.0AB
1 June	240AB	215BC	220AB	50.9ABC	49.2B	47.9AB
Mean	249a	225b	225b	53.8a	50.5ab	47.7b

† In a column, means followed by the same upper case letter are not significantly different by LSD with $\alpha = 0.05$.
‡ For each three mean measurement in this row followed by the same lower case letter, the means are not significantly different by LSD with $\alpha = 0.05$.

applied with caution. The year effect, which was mostly the moisture effect, only interacted for yields of P and K. To elucidate the complexity of carryover effects of winter species and its management on bermudagrass yield, the means for the factorial arrangement of winter treatments, three forages × five harvest systems, are presented with LSD tests for significant differences of means (Table 2).

Averaged over the five harvest systems, yields of hay, P, K, Mg, Mn, Fe, Zn, and Cu were significantly greater following the berseem clover cover than that following red clover or ryegrass of (Table 2). The average yields of bermudagrass N following legumes red clover and berseem clover are not significantly different but are significantly greater than that following ryegrass, reflecting the symbiotic N activity of the legume. The Ca yield of red clover was significantly greater than that of berseem clover or ryegrass.

Averaged over the three winter forages species, the bermudagrass hay yield was 9.86, 11.34, 10.89, and 12.05 Mg ha^{-1} for the two-harvest-day systems of 1 April, 15 April, 1 May, and 15 May, respectively. The single harvest on 1 June harvest yielded 10.30 Mg ha^{-1}. Thus, shortening or lengthening the time between the first and second harvest in the spring for the two-harvest-day system did not consistently increase or decrease yield. When analyzed for each cover crop, the highest yielding harvest was 15 May for P and Zn and 15 April for K and Cu. The complexity in the response of species as affected by winter harvest date is shown by the fact that the 15 May and 15 April harvest dates were never significantly different except for hay yield of berseem clover, but the intermediate 1 May yield was sometimes significantly less than that of 15 May or 15 April.

Earlier, Rowe and Fairbrother (2003) determined the best harvest date for winter forage productivity of hay and most nutrients was the two-harvest-day system of 1 April and 1 June, which maximizes the time between the two harvests. In contrast, the summer bermudagrass yield of P for the 15 May harvest was 28, 15, and 15% greater than the 1 April harvest for berseem clover, red clover, and ryegrass, respectively, and the yield of Zn was 28, 16, and 15% greater for 15 May harvest of berseem clover, red clover, and ryegrass, respectively, than for 1 April harvest. For Cu, the 15 April harvest was 17, 16, and 20% greater than the 1 April harvest for berseem clover, red clover, and ryegrass, respectively.

Any interaction or competition between two crops grown in tandem in the 12 mo management system was not predictable. An aggressive cover crop with a closed canopy is expected to limit radiant heating of soil surface and shaded bermudagrass stubble is not expected to break dormancy. It is speculated that the 15 May harvest may have opened the canopy at a critical time resulting in breaking of dormancy in the bermudagrass.

Annual Performance

Tests of summer performance and tests of winter performance are informative but the critical objective for farming is to maximize the annual extraction of environmentally important manure nutrients. Research

Table 3. Annual yields of hay and nutrients for spring harvest of plots with five harvest cutting systems on previous winter cover crop of berseem clover (BC), red clover (RC), or annual rye grass (RG) followed by summer harvest of common bermudagrass on same plots.

	Hay yield			N			P			K		
First harvest date	BC	RC	RG	BC	RC	RG	BC	RC	RG	BC	RC	RG
	Mg ha^{-1}			kg ha^{-1}								
1 April	19.37B†	18.84AB	18.54AB	420A	392AB	301B	59.8B	51.5BC	51.4A	559BC	511AB	411A
15 April	20.31B	19.04AB	19.16A	429A	407AB	346A	66.6A	55.1AB	55.5A	635A	537A	444A
1 May	20.06B	19.29AB	17.06B	425A	417A	299B	63.5AB	57.6A	52.0A	593AB	543A	405A
15 May	22.4A	19.57A	19.24A	417B	408AB	316AB	63.5AB	55.5A	53.2A	589AB	523AB	426A
1 June	19.09B	18.02B	19.33A	364B	370B	290B	54.0C	48.8C	50.6A	518C	477B	409A
Means	20.26a‡	18.95b	18.66b	411a	399a	311b	61.5a	53.7b	52.6b	579a	518b	419c

	Mg			Mn			Ca			Fe		
Harvest date	BC	RC	RG	BC	RC	RG	BC	RC	RG	BC	RC	RG
	kg ha^{-1}			g ha^{-1}			kg ha^{-1}			g ha^{-1}		
1 April	33.9AB	32.2A	23.9AB	1919A	1707A	1546B	106.9AB	94.6A	54.7AB	1392A	1125A	991AB
15 April	36.8A	32.6A	26.4A	2069A	1826A	1867A	112.5AB	91.2A	58.1A	1262AB	1141A	1083A
1 May	35.2AB	34.4A	22.6B	1926A	1680A	1532B	111.7AB	92.8A	51.0B	1212AB	1217A	900B
15 May	36.0A	32.7A	25.4A	1869A	1753A	1839A	121.8A	93.8A	58.3A	1252AB	1140A	1025AB
1 June	31.2B	31.2A	24.7AB	1569B	1692A	1716AB	105.0B	97.1A	56.5AB	1085B	1092A	970AB
Mean	34.6a	32.6b	24.6c	1871a	1732b	1732b	111.6a	93.9b	55.7c	1241a	1143b	994c

	Zn			Cu		
	BC	RC	RG	BC	RC	RG
	g ha^{-1}					
1 April	440C	394BC	383AB	111.4ABC	107.9A	79.2AB
15 April	528A	444A	412A	119.4A	111.3A	90.0A
1 May	479ABC	427AB	361B	116.9AB	106.2AB	84.0AB
15 May	501AB	427AB	396AB	108.8ABC	103.1AB	77.7B
1 June	450AB	381C	391AB	107.4C	96.5B	78.8AB
Mean	479a	415b	389c	112.8a	105.0b	81.9c

† In a column, means followed by the same upper case letter are not significantly different by LSD with α = 0.05.
‡ For each three mean measurement in this row followed by the same lower case letter, the means are not significantly different by LSD with α = 0.05.

reported by Rowe and Fairbrother (2003) determined that the two-harvest-day system with harvests of 1 April and 1 June was usually the best system for harvesting the cover crop, but this was not the best date for the summer forage.

On an annual basis, the variation among years were modest in contrast to variation in either the summer or winter harvests. The annual yields of hay in 1998, 1999, and 2000 were 19.59, 20.92, and 17.36 Mg ha^{-1}, respectively. The average annual yields of plots classified by winter forage were 20.26, 18.95, and 18.66 Mg ha^{-1} for berseem clover, red clover, and ryegrass, respectively. For discussion, it is understood that the annual hay yield or nutrient yield of the berseem plots, for instance, is the yield of the berseem clover used as a winter annual and the summer yield of the bermudagrass from plots where berseem clover was grown the prior winter. Since plots were randomized each fall for planting of cover crop and for the management system, plot performance did not reflect any cumulative effects of treatments over more than 1 yr.

The analysis of variance tests of treatment effects for annual data (combined data of summer and winter production) indicates that effect of forage species was significant for all yields of the hay and all nutrients (Table 1). The three-way interaction with forage (year $\times$ forage $\times$ harvest) was not significant except for yield of Ca. The two-way interaction with harvest (harvest $\times$ forage) was significant only for yield of hay and Mn. Though the differences between average annual yields of forages were modest, the interaction of year and forage species was significant for all yields. Thus best forage is little affected by harvest system but varied between years. The main effect of harvest was significant for all variables except yield of Mg, and the interaction with year was significant for all variables.

Of great environmental concern are the fates of macro nutrients N and P and the micro nutrients Zn and Cu. For these critical elements, the greatest yield was the two-harvest-day of 15 April and 1 June with the single exception of N yield for a winter cover of ryegrass (Table 3). For the macro elements, the single 1 June harvest had the lowest yields but for the two micro nutrients, lowest yielding harvest was inconsistent.

Foci of this research are comparisons of the performance of the best winter cover crop and its management with the commonly used ryegrass and the determination of gain with harvesting a winter cover crop in addition to the summer crop. The advantage of using berseem clover, when averaged for all harvest systems, instead of the common winter cover of ryegrass was to increase mineral uptake of P by 16.9%, K by 38%, Mg by 40.7%, Mn by 8%, Ca by 100%, Fe by 25%, Zn by 23% and Cu by 37%. On average, the harvesting both the winter and summer forages using the best harvest system instead of harvesting only the summer forage had an enormous effect on the quantity of nutrient extracted from the soil. The annual harvest of N was increased by 82% (374 vs. 205 kg ha^{-1}), P increased by 76% (31.7 vs. 55.9), K increased by 90% (265 vs. 505), Mg by 95% (15.7 vs. 30.6), Mn by 67% (1061 vs. 1778), Ca by 158% (33.7 vs. 87), Fe by 80% (616 vs. 1109), Zn by 83% (233 vs. 427), and Cu by 97% (50.7 vs. 99.9).

CONCLUSIONS

Both the winter cover crop species and the harvest dates had large residual effects on the summer yields of common bermudagrass. Bermudagrass following the berseem clover winter cover had greater yields than the other two cover crops for all nutrients and hay. Yield of nutrients from bermudagrass was minimal with either the single harvest on 1 June or the two-harvest-day system of 1 April and 1 June. In contrast with the commonly used single harvest of ryegrass, use of the best two-harvest-day system increased P extraction by 28%, Zn by 28%, and Cu by 20%. On annual basis, annual berseem clover yields averaged over all harvest systems contained 17% more P, 23% more Zn, and 37% more Cu than that of the ryegrass.

Best harvest date either for production of summer forage or for production of winter forage was not the best system for the annual harvest. For the environmentally sensitive nutrients, N, P, Zn, and Cu, the best cover crop harvest was two-harvest-day system of 15 April and 1 June and the best winter cover crop was always the berseem clover. Inclusion of a winter cover crop harvest in addition to the summer harvest increased the annual mineral uptake from 66 to 150%.

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